Transmittal Letter to the United States Designated/Elected Office (DO/EO/US)

414 Rec'd PCT/PTO 19 OCT 2000

09/673687

Docket No.	:	**MR-14PCT**
U.S. Application No.	:	
International Application No	:	**PCT/EP99/02625**
International Filing Date.	:	**APRIL 19, 1999**
Priority Dates Claimed	:	**APRIL 23, 1998 and JUNE 5, 1998**
Title of Invention	:	**CIRCUIT FOR THE DYNAMIC CONTROL OF CERAMIC SOLID-STATE ACTUATORS**
Applicant(s) for (DO/EO/US)	:	**Uwe Knauß**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. X This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.
2. ___ This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U S C 371
3. X This express request to begin national examination procedures 35 U.S.C. 371 (f) at any time rather than delay examination until the expiration of the applicable time limit set forth in 35 U.S.C 371(b) and PCT Articles 22 and 39(1).
4. ___ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date
5. X A copy of the International Application as filed [35 U.S.C. 371(c)(2)],
   a) X is transmitted herewith (required only if not transmitted by the International Bureau).
   b) ___ has been transmitted by the international Bureau.
   c) ___ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. X A translation of the International Application into English [35 U S.C.371(c)(2)].
7. ___ Amendments to the claims of the International Application under PCT Article 19 [35 U.S.C.371(c)(3)].
   a) ___ are transmitted herewith (required only if not transmitted by the International Bureau).
   b) ___ have been transmitted by the International Bureau.
   c) ___ have not been made; however, the time limit for making such amendments has NOT expired
   d) ___ have not been made and will not be made
8. ___ A translation of the amendments to the claims under PCT Article 19 [35 U.S.C.371(c)(3)].
9. X An oath or declaration of the inventor(s) [35 U.S.C 371(c)(4)]. UNSIGNED
10. ___ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 [35 U S.C 371(c)(5)].

Items 11. to 16. below concern other document(s) or information included:

11. X An Information Disclosure Statement under 37 C.F.R. 1.97 and 198
12. ___ An Assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3 31 is included.
13. X A FIRST preliminary amendment.
    ___ A SECOND or SUBSEQUENT preliminary amendment.
14. ___ A substitute specification.
15. ___ A change of power of attorney and/or address letter.
16. X (other items or information) **Three sheets of drawings, PTO-1449 w/3 references and** International Search Report

EXPRESS MAIL No.: **EL 599 503 225 US** Deposited: **October 19, 2000**

I hereby certify that this correspondence is being deposited with the United States Postal Service Express mail under 37 CFR 1 10 on the date indicated above and is addressed to the Commissioner of Patents and Trademarks, Washington, DC 20231.

Fr Kueffner

Friedrich Kueffner

October 19, 2000
Date

U.S. Application No. (if known, see 37 C.F.R. 1.50):
International Application No. : PCT/EP99/02625

Docket No: MR-14PCT

09/673687

17. X The following fees are submitted:

	CALCUL-ATIONS	PTO USE ONLY
BASIC NATIONAL FEE [37 CFR 1.492(a)(1)-(5)]:		
X Search Report has been prepared by the EPO or JPO.......... $ 840.00		
__ International preliminary examination fee paid to USPTO [37 CFR 1 482]: .... $ 670.00		
__ No International preliminary examination fee paid to USPTO [37 CFR 1.482] but International search fee paid to USPTO [37CFR 1.445(a)(2):.......... $ 690.00		
__ Neither International preliminary examination fee [37 CFR 1.482] nor International search fee [37 CFR 1.445(a)(2]) paid to USPTO:.......... $ 970.00		
__ International preliminary examination fee paid to USPTO [37 CFR 1.482] and all claims satisfied provisions of PCT Article 33 (2) to (4):.......... $ 96.00		
ENTER APPROPRIATE BASIC FEE AMOUNT:	$ 840.00	
Surcharge of $ 130.00 for furnishing the oath or declaration later than __20 __30 months from the earliest claimed priority date [37 CFR 1.492(e)]	$ 840.00	
Claims / filed / Extra / Rate		
Total Claims 5 -20= x $ 18 =	$	
Indep. Claims 1 - 3= x $ 80.=	$	
Multiple Dependent Claims (if applicable) + $ 270.=	$	
TOTAL OF ABOVE CALCULATIONS:	$ 840.00	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity Statement must be filed also. [Note 37 CFR 1.9,1.27, 1.28] (divided by 2)		
SUBTOTAL:	$ 840.00	
Processing fee of $ 130.00 for furnishing the English Translation later than __20 __30 months from the earliest claimed priority date [37 CFR 1.492(f)]	$	
TOTAL NATIONAL FEE:	$ 840.00	
Fee for recording the enclosed assignment [37 CFR 1.21(h)] The assignment must be accompanied by an appropriate cover sheet [37 CFR 3.28,3 31]. $ 40.00 per property	$	
TOTAL FEES ENCLOSED:	$ 840.00	
AMOUNT TO BE REFUNDED:	Refunded	$
AMOUNT TO BE CHARGED:	Charged	$

a) X A check in the amount of **$ 840.00** to cover the above fees is enclosed.

b) _ Please charge my Deposit Account No. 11-1835 in the amount of $ to cover the above fees A duplicate copy of this sheet is enclosed.

c) X The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No **11-1835**. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 36 CFR 1.494 or 1.495 has not been met, a petition to revive [37 CFR 1 137(a) or (b)] must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO: Friedrich Kueffner
342 Madison Avenue
Suite 1921
New York, NY 10173

Friedrich Kueffner
Name

Fr Kueffner
signature

29,482
Reg. No.

October 19, 2000
Date

VERIFIED STATEMENT (DECLARATION)
CLAIMING SMALL ENTITY STATUS
(37 CFR 1.9(f) and 1.27(c)) -
SMALL BUSINESS CONCERN
DOCKET NO: MR-14PCT

I hereby declare that I am

☐ the owner of the small business concern identified below:

☐ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF CONCERN: **Physik Instrumente (PI) GmbH & Co.**

ADDRESS OF CONCERN: **Polytec-Platz 5 - 7, 76337 Waldbronn, Germany**

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to and remain with the small business concern identified above with regard to the invention, entitled CIRCUIT FOR THE DYNAMIC CONTROL OF CERAMIC SOLID-STATE ACTUATORS SIGNAL CONDUCTOR by inventor(s) Uwe Knauß described in

☒ the specification filed herewith

☐ application serial no. ________, filed ________.

☐ patent no. ________, issued ________.

If the rights held by the above identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(d) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

***NOTE:** **Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)**

FULL NAME: ________

ADDRESS: ________

☐ INDIVIDUAL ☐ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING: DR. KARL SPANNER

TITLE OF PERSON OTHER THAN OWNER: ________

ADDRESS OF PERSON SIGNING: SCHAUINSLANDSTR. 5; 76337 WALDBRONN GERMANY

SIGNATURE: [signature]

DATE: 2000-11-09

VERIFIED STATEMENT (DECLARATION)
CLAIMING SMALL ENTITY STATUS
(37 CFR 1.9(f) and 1.27(c)) -
SMALL BUSINESS CONCERN
DOCKET NO: MR-14PCT

I hereby declare that I am . . .

☒ the owner of the small business concern identified below:

☐ an official of the small business concern empowered to act on behalf of the concern identified below:

NAME OF CONCERN: **GSG Elektronik GmbH**

ADDRESS OF CONCERN: **Gießereistraße 12, 83022 Rosenheim, Germany**

I hereby declare that the above identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

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☒ the specification filed herewith

☐ application serial no. ________, filed ________.

☐ patent no. ________, issued ________.

If the rights held by the above identified small business concern are not exclusive, each individual, concern or organization having rights to the invention is listed below* and no rights to the invention are held by any person, other than the inventor, who could not qualify as a small business concern under 37 CFR 1.9(d) or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

***NOTE:** **Separate verified statements are required from each named person, concern or organization having rights to the invention averring to their status as small entities. (37 CFR 1.27)**

FULL NAME: ________

ADDRESS: ________

☐ INDIVIDUAL ☐ SMALL BUSINESS CONCERN ☐ NONPROFIT ORGANIZATION

I acknowledge the duty to file, in this application or patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b))

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

NAME OF PERSON SIGNING: JUERGEN GRAMCZEWSKI

TITLE OF PERSON OTHER THAN OWNER: ________

ADDRESS OF PERSON SIGNING: Gießereistr. 12, 83022 Rosenheim

SIGNATURE: Jürgen Gramczewski

DATE: 20. Nov. 2000

09/673687

422 Rec'd PCT/PTO 19 OCT 2000

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

MR-14PCT

Applicant(s)	:	Uwe Knauß
Serial No.	:	NOT YET KNOWN (PCT/EP99/02625)
Int. Filed	:	APRIL 19, 1999
For	:	CIRCUIT FOR THE DYNAMIC CONTROL OF CERAMIC SOLID-STATE ACTUATORS

Assistant Commissioner for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

S I R:

In advance of the first office action, please amend the claims as follows:

IN THE CLAIMS

Claim 1, line 5, change "characterised in that" to --wherein--.

Claim 2, line 2, change "characterised in that" to --wherein--.

Claim 3, line 1, change "one of the previous" to --claim 1--;
line 2, delete "claims";
line 3, change "characterised in that" to --wherein--.

Claim 4, line 2, change "characterised in that" to --wherein--.

Claim 5, line 2, change "characterised in that" to --wherein--.

REMARKS

Claims 1 - 5 are in the application.

As a result of the foregoing amendment, the claims have been amended to remove improper multiple dependencies.

Any additional fees or charges required at this time in connection with the application may be charged to our Patent and Trademark Office Deposit Account No. 11-1835.

Respectfully submitted,

FK:ml
October 19, 2000
342 Madison Avenue
New York, NY 10173
(212) 986-3114

Friedrich Kueffner
Reg. No. 29,482

EXPRESS MAIL No.: **EL 599 503 225 US** Deposited: **October 19, 2000**

I hereby certify that this correspondence is being deposited with the United States Postal Service Express mail under 37 CFR 1.10 on the date indicated above and is addressed to the Commissioner of Patents and Trademarks, Washington, DC 20231.

Friedrich Kueffner

October 19, 2000
Date

09/673687

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Circuit Arrangement for the Dynamic Control of Ceramic Solid-State Actuators

Description

The invention relates to a circuit arrangement for the dynamic control of ceramic solid-state actuators, such as for example, piezotranslators with energy recovery by means of magnetic intermediate stores according to the preamble of Claim 1 as well as a control loop for operating a piezotranslator.

Piezotranslators are electrically controllable actuators whose functions can be attributed to the piezoelectric effect. Active sensors, so-called actuators, can perform the most delicate positioning movements with high accuracy from the subnanometer up to the millimetre range.

Under electrical aspects, a piezotranslator represents a capacitor whose charge has a proportional relationship to its expansion. Consequently, piezotranslators take up energy during the expansion process only. The expansion is maintained without further energy supply. Due to the high capacitance of the piezotranslators, however, a high output power of the driver circuit is required in the case of fast positional changes as they occur under dynamic operation conditions. The associated control electronics must therefore have special properties for each application case and has to be optimised in order to ensure the successful employment of a piezotranslator.

In control processes for the dynamic piezocontrol in which the actuating element must follow up fast changes of a reference variable, it is desired that the amplitude of the movement characteristic agrees with the input signal as close as poss-

ible. However, such a linear transfer behaviour cannot be ensured for frequencies up to any magnitude, but is limited, on the one hand, by the resonance frequency of the translator or the entire actuating system, respectively, and by the output power of the amplifier, on the other hand.

Due to the hysteresis phenomena of a piezotranslator the absolute expansion of the actuating element can be determined only inaccurately via the applied amplified input voltage of the amplifier. The resulting expansion has an inherent error of up to 10%, both with respect to its absolute value and to its relative movements. In order to eliminate this error, it is known to provide closed control loops, i.e. a measuring system for the expansion and control electronics which control the operating voltage in accordance with a comparison of the reference variable and the actual value. Closed positioning control loops are therefore provided with external probes in order to be able to determine the position.

Due to the fact that piezotranslators can electrically be described as capacitors, as mentioned above, onto which electric charges must either be applied or from which said charges must be withdrawn for the purpose of a length variation, which for example can be realised by means of a switch, charging or discharging between the piezotranslator, on the one hand, and the charging current circuit, on the other hand, will inevitably result in power losses, if this is done via controllable variable resistors, e.g. transistors.

From the final report of the joint project "Entwicklung leistungsoptimierter, hybrider Hydraulikkomponenten auf der Basis piezoelektrischer Aktuatoren" (Development of Power-Optimised Hybrid Hydraulic Components on the Basis of Piezoelectric Actuators) of the Institut für Fertigungstechnik und spanende Werkzeugmaschinen (Institute of Manufacturing Engineering and

Metal Cutting Machine Tools), Hanover, Germany, November 1996, it is known to design digital control amplifiers for driving piezoelectric actuators, which are provided with a controlled energy recovery capacity. The known final stage preferably includes inductively coupled coils in order to increase the efficiency of the energy recovery.

In the known circuit arrangement two separate magnetic intermediate energy stores are provided, with the energy stores being switched by a controller in a clocked manner, in order to achieve a predetermined output voltage curve of the control circuit. At the piezotranslator a voltage-dependent non-linear charging of the capacitance will result, with the available current decreasing upon reaching the supply voltage. Due to the circuit arrangement as two separate blocking transformers, only one direction each of the output current can be driven.

In order to obtain a desired linear voltage increase at the piezotranslator, the storage volume of each store must be designed extremely large in the state of the art. The reason of this is that the blocking transformer must be dimensioned according to the smallest voltage increase ΔU at the range limits of the operating voltage. In the middle output range, however, the available storage volume cannot be utilised so that a correspondingly implemented output amplifier does not operate efficiently.

With respect to the control of piezotranslators in actual applications, the actual momentary value of the output voltage supplied to the piezotranslator is determined by means of a control loop. This is to compensate for existing deficiencies of the control circuit or the final stage, respectively, such as its non-linearity, temperature drift, and frequency dependence, as well as any undesired behaviour of the connected

piezotranslator because of the already mentioned voltage hysteresis.

In this context, it has been known to apply part of the piezo output voltage as the actual value to the input of an error amplifier, or to use an exact physical measuring system which yields an output voltage as the actual value. The desired reference variable is supplied to the input of the error amplifier, with the output of the amplifier being connected to the control circuit itself.

The above described controller concept achieves satisfactory results with arrangements without energy recovery, which are mostly equipped with a conventional loss-inherent final stage of the type of controlled series resistors. However, problems occur with a corresponding use in energy recovering control circuits. The reason for this is the considerable inductances which are responsible for the desired energy recovery and which are connected in series to the piezotranslator. Together with the piezotranslator which represents a capacitor these form a high-quality series or resonance circuit. Depending on the type or size of the translator and employed inductor, its resonance frequency is mostly within the frequency band in the range from 1 to 5 kHz, which is of interest for the amplifier operation. The series resonance circuit in turn causes a high increase of the amplification in the resonance range, together with an undesired phase shift in the working band of the control loop approaching the critical 180° limit, which affects the compensation. From this, an undesired post-pulse oscillation or self-oscillation results. The desired flat amplitude characteristic of the overall system up to the upper working frequency range is therefore no longer achievable.

Therefore, it is the object of the invention to provide a circuit arrangement for the dynamic control of piezotrans-

lators with energy recovery as well as an improved control loop for the operation of piezotranslators, which allow the almost linear charging of the piezotranslator over the entire voltage range and at the same time the optimisation of the energy recovery with a small installation size of the implemented circuit. Simultaneously, energy storing elements such as capacitors or accumulators must be able to be operated at a maximum piezotranslator supply voltage so that the return currents can be maintained correspondingly low. With respect to the control loop, it is essential to prevent points of resonance in the working and transfer range so that any self-oscillation can effectively be avoided.

The object of the invention is solved by means of a subject matter as it is defined in the valid Claim 1 as well as in Claims 4 and 5 as far as the closed loop control is concerned. The remaining dependent claims represent at least suitable embodiments or developments of the invention.

The basic idea of the invention is to form the control circuit for the dynamic operation of piezotranslators as a half-bridge circuit with a single series coil as an intermediate energy store. In this case, the maximum available current for charging and discharging the piezotranslator is identical with the maximum current of the series coil. Such a limitation occurs unchanged and at a constant limit current over the entire range of the piezo output voltage. For the capacitance of the piezotranslator the constant limit current causes a constant voltage increase so that the storage capacity of the intermediate energy store is uniformly and fully utilised over the entire working range. The installation size can be reduced due to the use of a single series coil, with the indirect consequence of a cost reduction.

According to the invention, a direct-current superimposed single coil is employed as an intermediate energy store, with the coil to be considered as a forward converter under the aspect of its effect. The coil direct current flows during the entire activation period and is modulated by a high-frequency alternating current with a relatively small amplitude at the working cycle of the half-bridges, i.e. of the employed switches, at a frequency of essentially 100 kHz.

By means of the inventive arrangement of a single inductive magnetic intermediate store in the secondary circuit which is connected in series with the piezotranslator and with the secondary circuit being designed as a half-bridge, it is possible to significantly increase the efficiency of the power final stage formed in this manner. Due to the fact that there is no internal electrical isolation, the losses can be reduced further. Also otherwise present drawbacks due to voltage losses at the energy recovery diodes do no longer occur in a comparable magnitude. A transfer of the entire energy in the piezotranslator in each modulation wave to the primary side and back again as this is the case in the state of the art is no longer necessary.

Due to the fact that the only energy store is located on the secondary side and is subjected to the high piezo voltage which, depending on the translator type, is between 100 and 1200 V, the currents during the energy recovery can be kept low. With respect to circuit engineering, the only intermediate store can be arranged in a spatially close relationship with the piezotranslator so that electromagnetic radiated noise can be reduced to a minimum. A still better electromagnetic compatibility results from the effective modulation current which is superimposed by only a low high-frequency alternating current according to the external cycling of the half-bridges. By a corresponding dimensioning of the inductive

intermediate store, the superimposed alternating current is in the order of essentially 10% of the modulation current so that the residual ripple will be greatly reduced.

Another basic idea of the invention is that when using MOSFETs as switches, the negative effects of existing internal inverse diodes can be avoided. For this purpose, the invention proposes to connect an external blocking diode in series with the clearance between open contacts and to bridge this series connection by an oppositely poled commutating diode. This additional diode combination prevents the inverse operation of the MOS transistors by its internal inverse diode and allows a quasi external inverse operation by the commutating diode which is oppositely poled with respect to the external blocking diode.

The additional diodes have a shorter recovery time relative to the MOS transistor in order to considerably improve the operation of the modified half-bridge circuit under the aspect of the switching frequency.

In the inventive control concept and according to another basic idea of the invention, a current sensor for determining a control voltage which is proportional to the output current is arranged for controlling the piezotranslator. This current sensor is connected with the input of a first controller, with the second input of the first controller being applied to the output of a second controller at whose inputs a given reference variable corresponding to the physical position of the piezotranslator and the reduced output voltage is applied.

Accordingly, the control concept consists of two nested, separate control loops, i.e. an inner and an outer control loop. The inner control loop encompasses the control circuit proper, including a potentially critical point of resonance

which is formed by the magnetic energy stores which are provided there in any form and the capacitive load of the piezotranslator.

By means of the outer control loop it is possible to achieve the characteristic of the output voltage which is defined by the input signal, i.e. the reference variable, of the position and expected with an amplified amplitude at the amplifier output.

Due to the fact that the inner control loop has already eliminated the point of resonance and the associated additional phase shift in the working frequency range, the outer control loop can be optimised in a simple manner. As a whole, the design of the circuit arrangement for controlling purposes offers an improved overall transfer behaviour. The amplitude characteristic is uniform over the entire frequency range, including the point of the critical LC circuit and drops without transition point. The phase characteristic has a phase margin of at least 50° and is not critical, while it is possible to keep the time behaviour at the maximum system dynamics free from resonances and overshooting.

As explained above, the inner control loop operates by utilising a current proportional sensor signal, with a current transformer being provided for this purpose. This current transformer can be realised by a simple series resistor in the return line of the load current or by a simple transformer circuit. The inner control loop thus enforces a current of a predetermined magnitude at the output of the final stage or of the control circuit, respectively, which flows into the load and which can be controlled in its time characteristic by the specified reference variable. Any additional loads connected with the capacitive piezotranslator load, such as, for

example, a storage coil, have no influence on the common load current and cannot cause resonance phenomena.

Due to the fact that the voltage which is normally building up at the piezotranslator is defined by the integral of the current, the now controlled current, however, no longer has a point of resonance, it is possible to keep the piezovoltage, too, free from resonances. The inductance of the intermediate store, which is introduced for energy recovery, is no longer detected by the control behaviour of the inner control loop as a resonance-generating component and thus eliminated to the outside.

In an embodiment of the invention, an additional positioning control of the system is performed according to another basic idea, in that a third controller is provided at the first input of which the reference variable of the physical position of the piezotranslator and at the second input of which a physical actual value of the piezotranslator, which is detected via a sensor, is applied, with the output of the third controller being connected with one of the inputs of the above mentioned second controller.

The dynamic behaviour of the control system with inner and outer control loop can be improved according to another basic idea of the invention in that the second controller feeds back the integral of the piezotranslator current instead of controlling an output voltage which is proportional to the reference variable. This alternative feedback can be activated in a frequency dependent manner.

In a preferred embodiment, the integration value is used at frequencies of essentially > 10 Hz, and at frequencies of < 10 Hz, the mentioned voltage feedback is performed.

The described advantage of the improved pilot control also has a positive influence of those control loops in which an additional positioning control by means of a further controller is dispensed with. These advantages are particularly effective at the upper limit of the working frequency range where the loop amplification must be reduced because of the operational stability and is therefore too low for an effective error compensation.

The invention will be described in more detail by means of embodiments as well as with reference to the figures in the following.

In the figures:

Fig. 1 shows a circuit diagram of the circuit arrangement for the dynamic control of piezotranslators with energy recovery;

Fig. 2 shows a configuration of the MOSFET switch with an external blocking diode and a commutating diode oppositely poled relative to same;

Fig. 3 shows a block diagram of the control system with an inner and an outer control loop comprising the optional possibility to adapt the outer control loop to the integration value of the current;

Fig. 4 is an illustration of the control system with additional positioning control;

Fig. 5 shows a block diagram for reducing the low frequency voltage noise; and

Fig. 6 shows a block diagram of a known fine control.

The circuit diagram of Fig. 1 shows a circuit arrangement for the dynamic control of piezotranslators.

As can be seen, a single inductive intermediate store 1 is connected in series with the piezotranslator 2. The illustrated secondary circuit shows a half-bridge arrangement, with switches 3 and 4 being externally clocked with up to 100 kHz. The switches 3 and 4 are bridged by energy recovery diodes 5 and 6. In the configuration of the switches 3 and 4 as MOSFETs such diodes are integral members of this transistor family.

Voltage sources 7 and 8 for one half-bridge each are formed by a switched-mode power supply known per se and comprise suitably dimensioned storage capacities.

The coil direct current is superimposed by a low, high-frequency direct current of small amplitude in the working cycle of the half-bridges. The only energy store 1 reduces the storage volume with respect to size and is operative both during charging as well as discharging of the piezotranslator's capacitance, i.e. over the entire operating time.

Compared to the known state of the art, the switching losses according to the arrangement of the embodiment are considerably lower. In order to obtain the intended linear output voltage curve, the switches 3 and 4 are activated by a corresponding controller with high cycling or switching frequency. The ratio of the closing times of switches 3 and 4 defines the working direction "charging" or "discharging". At the piezotranslator 2 a linear charging of its capacitance in the entire voltage range from 0 to UB max. is obtained.

With reference to Fig. 2, a preferred external wiring of a MOS transistor or a MOSFET, respectively, to be used in the circuit arrangement according to Fig. 2, will be explained in

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Voltage sources 7 and 8 for one half-bridge each are formed by a switched-mode power supply known per se and comprise suitably dimensioned storage capacities.

The coil direct current is superimposed by a low, high-frequency direct current of small amplitude in the working cycle of the half-bridges. The only energy store 1 reduces the storage volume with respect to size and is operative both during charging as well as discharging of the piezotranslator's capacitance, i.e. over the entire operating time.

Compared to the known state of the art, the switching losses according to the arrangement of the embodiment are considerably lower. In order to obtain the intended linear output voltage curve, the switches 3 and 4 are activated by a corresponding controller with high cycling or switching frequency. The ratio of the closing times of switches 3 and 4 defines the working direction "charging" or "discharging". At the piezotranslator 2 a linear charging of its capacitance in the entire voltage range from 0 to UB max. is obtained.

With reference to Fig. 2, a preferred external wiring of a MOS transistor or a MOSFET, respectively, to be used in the circuit arrangement according to Fig. 2, will be explained in more detail.

For circuit engineering reasons, the mentioned switches 3 and 4 are employed in the final stages of the half-bridge according to Fig. 1. The connection of the intermediate store 1 is alternately made with the upper or lower supply voltage UB/2, respectively. Not more than one of the two switches 3; 4 is closed. Because of the configuration of the circuit arrangement, currents with both positive and negative sign occur at the switches 3 and 4. For example, a current flows through the closed switch at times which increases the average current in the intermediate store 1, which returns half a modulation period later as a so-called commutating current for the purpose of energy recovery.

In the case in which MOS transistors are used for the switches 3 and 4, the current return flow is not effected via the active element itself but via an internally provided parasitic inverse diode which is an inevitable element of the transistor. These inverse diodes need a considerable recovery time after having been temporarily subjected to a return current so that the MOS transistor can only be switched off with a long delay time. Therefore, said transistor, following an application of a return current, behaves like a complete short circuit over some time.

For operational reasons, long-term return currents flow in the described half-bridge for energy recovery, which originate from the energy store 1 and have been induced there, which pulsate with the modulation frequency and which, without external measures, continue for a multiple of the desired high clock frequency of 100 kHz. If such a current flows e.g. through the switch 3 inversely into the upper supply voltage UB/2, and if the switch 3 is then blocked for operational reasons and the switch 4 is closed, then a short circuit occurs in the clearance between open contacts 3, 4 during the recovery time of the switch 3 because the switch 3 cannot open

the physical position of the piezotranslator, on the one hand, and the fed back voltage of the secondary circuit or the integral of the piezotranslator current, on the other hand, are applied.

The final stage 18 which is controlled by the output of the first controller 13 via a filter 17 can correspond to the circuit arrangement for controlling according to Fig. 1, but can also be formed by two blocking transformers according to the state of the art. The inner control loop which is formed by the current sensor 12 and the first controller 13 comprises the final stage 18 including a potentially critical point of resonance which is generated by energy stores provided for energy recovery and the capacitive load of the piezotranslator 2. For the purpose of generating the characteristic of the output voltage which is specified by the reference variable of the position and expected at the amplifier output with an amplified amplitude, the outer control loop comprising the second controller 14 with voltage feed-back is provided.

In the case where the integral of the piezotranslator current is fed back, the outer control loop comprising the second controller 14 causes a correspondingly pre-distorted characteristic of the amplifier output voltage which, however, corresponds to an essentially similar characteristic of the movement which is actually carried out by the piezotranslator 2 by the reference variable of the position without any hysteresis interference of the translator.

The embodiment according to fig. 4 shows an additional positioning control, with reference being made to the explanations in conjunction with Fig. 3 with respect to the inner and outer control loop. The same elements are identified by identical reference numerals.

A third controller 19 is provided for positioning control, at whose first input the reference variable of the physical position of the piezotranslator 2 and at whose second input a physical actual value sensed via a sensor 20 of the piezotranslator 2 is applied. The output of the third controller 19 is connected with a corresponding input of the second controller 14, if required, by connecting an amplifier-filter combination 21 in between.

Switching and actuating the switches 3 and 4 with a clock frequency of approx. 100 kHz generates a residual ripple in the coil 1 and thus in the output current. Although this high-frequency ripple at the piezotranslator 2 will no longer result in a uniform physical movement, it nevertheless causes a considerable mechanical stress, the extent of which depends on the type of ceramic, acting on this actuator element due to heavy partial oscillations.

According to a further embodiment a reduction of the current ripple which is superimposed on the output current can be achieved as follows.

A series resonance circuit, formed by an inductance and a capacitor, is arranged in parallel with the piezotranslator. The two components make up a resonance circuit which is adjusted to the high clock frequency of 100 kHz. It diverts the high-frequency current to ground and thus past the piezotranslator 2. The advantage resulting therefrom can either be utilised for the piezotranslator 2 under the aspect of service life or for a further reduction of the inductance 1.

As shown in Fig. 5, there is the possibility of reducing the low-frequency output voltage noise of the circuit arrangement by means of a circuit expansion.

Due to the rapidly changing high switching currents and voltages an interference voltage in the form of a low-frequency noise voltage occurs, independently of and superimposed on the desired modulation, at the output of an amplifier which is connected for energy recovery reasons. This is the case, in particular, if the high-frequency pulse sequence supplied to the final stage by the controller includes a so-called jitter, i.e. a statistically distributed jitter of the switching times included therein.

The noise voltage which is undesirably superimposed on the desired piezovoltage affects maintaining of a stable physical position of the actuating element piezotranslator in the case of being controlled by a fixed reference variable. However, corresponding mechanical variations are superimposed on a desired modulation as well.

It was already proposed to avoid the problem of high-noise switched amplifiers by connecting an additional final stage for fine control between said amplifiers and the load proper. This final stage operates to the conventional, loss-inherent, analog technology in the form of variable resistors and generates a relatively noise-free output signal. Due to the fact that the downstream connected final stage with the coarsely pre-controlled output voltage of the connected amplifier, which for this purpose, can be adjusted higher by a fixed small amount, only a negligible power loss will occur there. Contrary to the more frequent ohmic loads which do not require active discharging, said discharging must be included in suitable amplifiers for the inductive piezotranslators.

According to Fig. 6 it is known to use two completely switched amplifiers 41 and 42 in the conventional manner (as in Fig. 3, but without internal current control) in order to provide the required positive and negative supply voltage in a correspond-

ing manner for the fine control of the downstream arranged analog final stage 43.

For this purpose, the assemblies 41 and 42 feed back their respective output voltages to the internal amplifier circuits 14 according to Fig. 3 and compare them with the reference variable of the physical position, but add a small fixed offset which offsets the amplifier 41 downwards by a small fixed amount and offsets the amplifier 42 upwards by the same amount.

The two capacitors 44 and 45, whose capacitances are low compared to the capacitance of the piezotranslator 2, provide the filtering of the switching frequency, which is required for the function of the connected amplifiers.

The downstream amplifier 43 with its own (not shown) control loop generates the correct output voltage at its output, again with only little noise, which is supplied to the piezotranslator 2.

The drawback of the above described circuit arrangement is that under control engineering conditions, it is possible to a limited extent only, to stably maintain a small difference of fixed magnitude between the two outputs of the amplifiers 41 and 42. This might be conceivable in the case of static mechanical reference variables and in the lower modulation range but is no longer possible in the range of a higher frequency modulation of approx. 2 kHz. The amplifier-specific and unavoidable phase shifts in the two amplifiers 41 and 42 hardly reach values of approx. 90° and a synchronisation in these two amplifiers can hardly be achieved.

Already a small phase difference between the amplifiers 41 and 42, however, is sufficient to exceed the desired small control

difference several times. Upon reaching the only insufficiently suppressed points of resonance, at the latest, the synchronisation problems become insurmountable. The principally known solution of noise reduction can therefore not be employed in the high frequency range of the modulation, which in fact is the interesting one.

With a limitation to the lower frequency range, however, the upstream energy-saving amplifiers 41 and 42 become rather meaningless, because only low power values occur due to the decreasing currents in the piezotranslator 2.

As shown in Fig. 5, according to another embodiment, only one amplifier 41a is formed instead of the amplifiers 41 and 42, which greatly reduces the overall expenditure.

The output voltage of this amplifier is still somewhat lower than the output voltage which is expected at the piezotranslator 2. By means of the additional provision of an internal current control loop 13 (according to Fig. 3), when compared to the amplifier 41, any points of resonance are effectively suppressed in the amplifier 41a.

The downstream final stage 43 for fine control is adopted, as is the capacitor 44.

The known upper amplifier 42 (Fig. 6) is replaced by an additional new voltage source 46. This is also connected with the output of the amplifier 41a and includes an internally installed capacitor of adequate magnitude for blocking.

The magnitude of the direct voltage source 46 corresponds to the previously controlled difference between the outputs 41 and 42, and is small compared to the maximum working voltage which can be supplied to the piezotranslator 2. It corresponds

essentially to twice the peak value of the noise voltage occurring at the output of the amplifier 41.

The output of the dissipative amplifier 43 is controlled by means of a first control loop by feeding back the voltage of the piezotranslator 2, its charge integral, or a mechanical sensor 20 (similar to Fig. 3 or 4) to the correct, noise-free value which is amplified relative to the reference variable of the physical position.

The inner current control loop 13 is located in the controller of the amplifier 41a. For controlling the output voltage of the amplifier 41a, however, a separate voltage comparison is carried out independently of the amplifier 43, as this is provided for in the state of the art. The sole parameter which is responsible for the controller 14 is the difference between the output voltages of the amplifiers 41a and 43, which is directly picked-off and supplied to the controller 14. Furthermore, the comparison is no longer made against the reference variable of the physical position, but against a fixed reference voltage with a magnitude of half the source voltage.

Thus, the available supply voltage reserve for the amplifier 43 is no longer provided by the difference of the independent measurement of two parameters, which might easily be invalidated by phase errors, but is directly measured and controlled.

The advantage which results from the embodiment according to Fig. 5 lies in the following. The use of the fixed voltage source 46 allows the complete omission of a second switching amplifier 42 which is considerably more expensive. Thereby, the power losses occurring therein are avoided. By means of the resonance-suppressed current control in the amplifier 41a together with the directly controlled symmetry of the working voltage for the amplifier 43, the operation over the entire

previous frequency range of the amplifier 41a is possible without any restriction.

All in all, the inventive circuit arrangement as well as the proposed control concept allow the exact control of piezo-translators as electrical actuating elements with a moderate circuit expenditure, with an optimisation of the energy recovery being possible at the same time. By designing the control loop with or without an additional desired positioning control, effects of undesired non-linearities of the piezo-translator, such as the hysteresis effect and the long-term drift, can be prevented.

List of Reference Numerals

1	Intermediate store
2	Piezotranslator
3, 4	Switches
5, 6	Recovery diodes
7, 8	Voltage sources UB/2
9	MOSFET
10	External blocking diode
11	Commutating diode
12	Current sensor
13	First controller
14	Second controller
15	Amplifier
16, 17, 22	Filters
18	Final stage
19	Third controller
20	Mechanical position sensor
21	Amplifier-filter combination
41, 42	Switched amplifiers
41a	Switched amplifier including current control
43	Analog amplifier in low-noise configuration
44, 45	Filter capacitors
46	DC voltage source

ART 34 AMDT

09/673687

AMENDED CLAIMS

22 1

422 Rec'd PCT/PTO 19 OCT 2000

3/prts.

New Claims

1. A circuit arrangement for the dynamic control of piezotranslators (2) with energy recovery by means of a single inductive intermediate store (1) which is arranged in series with the piezotranslators (2) as well as by clocked switches, characterised in that
for achieving a predetermined linear voltage characteristic at the piezotranslator (2), the secondary circuit is designed as a half-bridge consisting of the switches (3, 4) at whose output the inductive intermediate store (1) is arranged in series with the piezotranslator (2), with the switches (3, 4) being externally controlled and operated at a high cycle or switching frequency in such a manner that the intermediate store is alternately connected with an upper or lower supply voltage ((UB/2) at the most, with the series connection of piezotranslator (2) and inductive intermediate store (1) carrying a superimposed bridge direct current.

2. The circuit arrangement according to Claim 1, characterised in that
the switches (3, 4) are formed as MOS transistors (9), with an external diode (10) being connected in series with the clearance between contacts, and this series connection being bridged by a commutating diode (11) which is oppositely poled to the diode (10).

3. The circuit arrangement according to one of the previous claims,
characterised in that
a current sensor (12) for generating a control voltage which is proportional to the output current of the final stage (18) is arranged in the secondary circuit of the piezotranslator

(2) for controlling the arrangement, with the control voltage being connected with a first input of a first controller (13), the second input of the first controller (13) being applied at the output of the second controller (14), at whose two inputs a predetermined reference variable according to the physical position of the piezotranslator (2) and an actual value which is proportional to the output voltage of the final stage (18) are applied.

4. The circuit arrangement according to Claim 3, characterised in that
a third controller (19) is provided for the positioning control, at whose first input the reference variable of the physical position of the piezotranslator (2) and at whose second input a mechanical actual value which is detected via a sensor (20) of the piezotranslator (2) are applied, with the output of the third controller (19) being connected with one of the inputs of the second controller (14).

5. The circuit arrangement according to Claim 3, characterised in that
the second controller (14) feeds back the integral of the piezotranslator current in lieu of a voltage which is proportional to the output voltage of the final stage (18).

Abstract

The invention relates to a circuit arrangement for the dynamic control of ceramic solid-state actuators, such as piezotranslators with energy recovery by means of magnetic intermediate stores and/or storage capacitors as well as by clocked switches. For achieving a predetermined linear voltage characteristic at the piezotranslator, according to the invention, a single inductive intermediate store is arranged in the secondary circuit, which is connected in series with the piezotranslator, and the secondary circuit is designed as a half-bridge. The switches provided in the respective half-bridge are controlled at a high cycle or switching frequency by an external controller, with the series connection of piezotranslator and inductive intermediate store furthermore carrying a superimposed bridge direct current in order to ensure the desired charging of the capacitance of the piezotranslator, on the one hand, and to optimise the energy recovery, on the other hand.

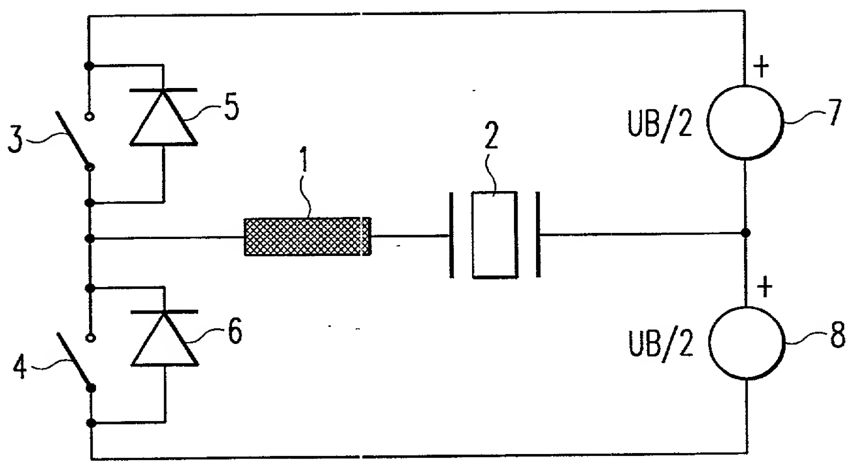


Fig. 1

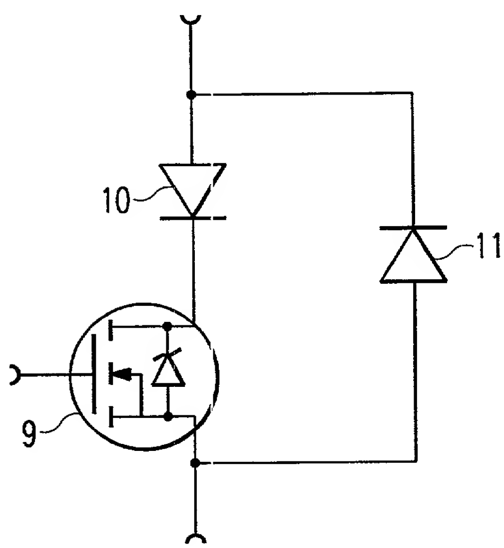
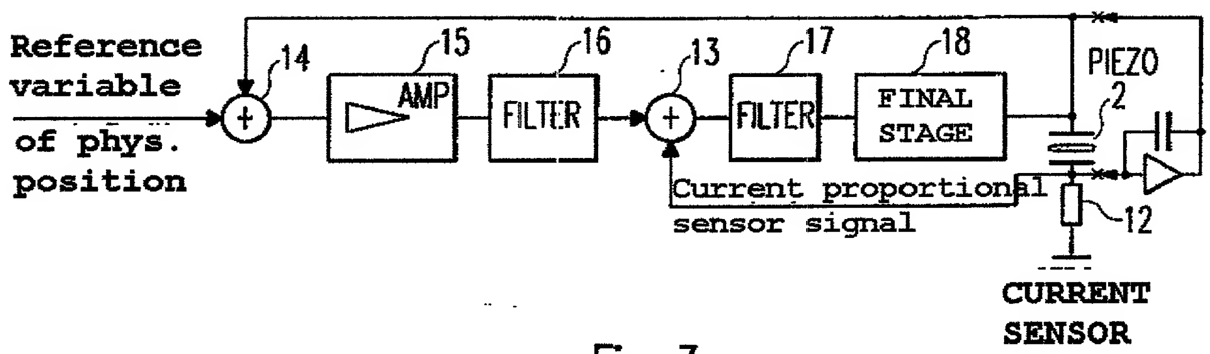


Fig. 2


Reference variable of phys. position
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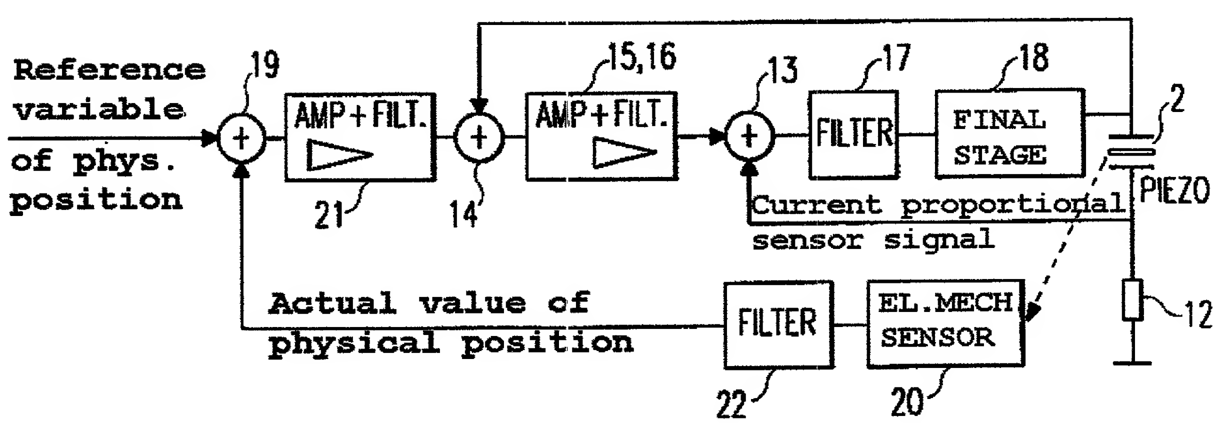
15
AMP
16
FILTER
13
17
FILTER
18
FINAL STAGE
PIEZO
2
Current proportional sensor signal
12
CURRENT SENSOR

Fig. 3


Reference variable of phys. position
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AMP+FILT.
21
14
15,16
AMP+FILT.
13
17
FILTER
18
FINAL STAGE
2
PIEZO
Current proportional sensor signal
Actual value of physical position
FILTER
22
EL.MECH SENSOR
20
12

Fig. 4

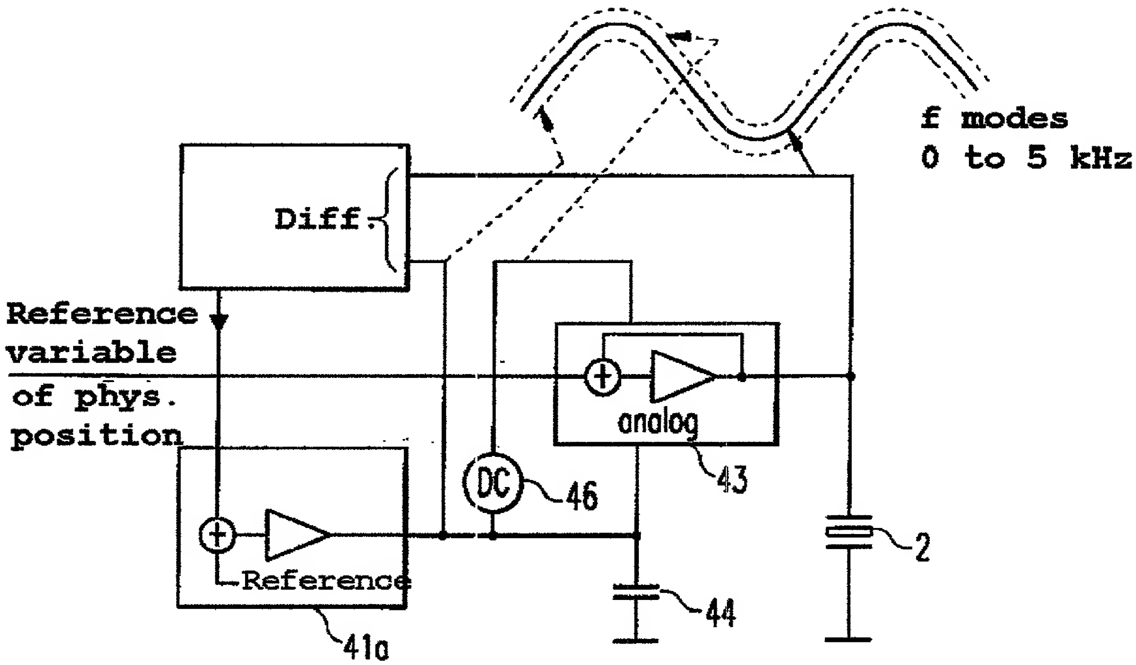
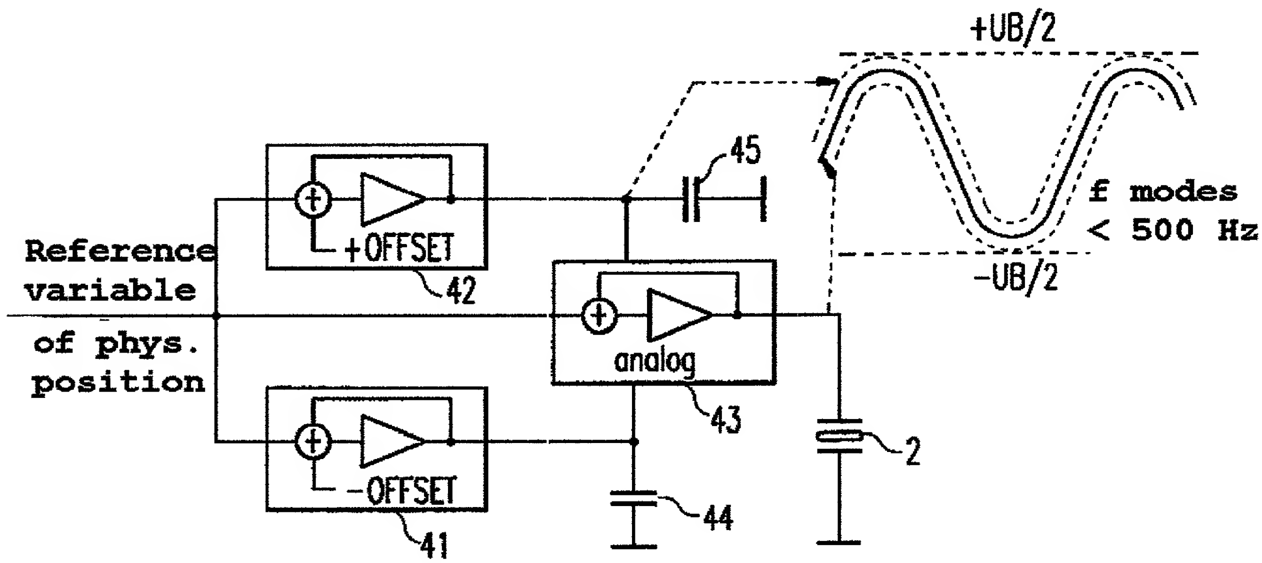

f modes
0 to 5 kHz
Diff.
Reference
variable
of phys.
position
analog
43
DC
46
2
Reference
44
41a

Fig. 5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45
f modes
< 500 Hz
-UB/2
+OFFSET
42
Reference
variable
of phys.
position
analog
43
2
-OFFSET
44
41

Fig. 6

COMBINED DECLARATION FOR PARENT APPLICATION AND POWER OF ATTORNEY *(includes Reference to PCT International Applications)*	Attorney's Docket No. **MR-14**

As a below named inventor, I hereby declare that:
My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled: **CIRCUIT FOR THE DYNAMIC CONTROL OF CERAMIC SOLID-STATE ACTUATORS**

the specification of which (check only one item below):

[ ] is attached hereto.

[ ] was filed as United States application

Serial No. ______
on ______,
and was amended
on ______ (if applicable).

[X] was filed as PCT international application

Number **PCT/EP99/02625**
on **APRIL 19, 1999**,
and was amended under PCT Article 19
on ______ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

PRIOR FOREIGN/PCT APPLICATION(S) AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. 119:

COUNTRY *(if PCT, indicate PCT)*	APPLICATION NUMBER	DATE OF FILING *(day, month, year)*	PRIORITY CLAIMED UNDER 35 USC 119
GERMANY	**198 18 273.2**	**23 APRIL 1998**	[X] YES [ ] NO
GERMANY	**198 25 210.2**	**5 JUNE 1998**	[X] YES [ ] NO

PTO-1391 (REV. 10-83)

U.S. DEPARTMENT OF COMMERCE - Patent and Trademark Office

Docket No. **MR-14**

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of the application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty of disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occured between the filing date of the prior application(s) and the national or PCT internation filing date of this application:

PRIOR U.S. APPLICATIONS OR PCT INTERNATIONAL APPLICATIONS DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. 120:

U.S. APPLICATIONS			**STATUS *(CHECK ONE)***		
U.S. APPLICATION NUMBER		U.S. FILING DATE	PATENTED	PENDING	ABANDONED
PCT APPLICATIONS DESIGNATING THE U.S.					
PCT APPLICATION NO.	PCT FILING DATE	U.S. SERIAL NO.			

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. *(List name and registration number)*

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Combined Declaration For Parent Application and Power of Attorney (Continued) *(includes Reference to PCT International Applications)*	Docket No. **MR-14**

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2	POST OFFICE ADDRESS	*Post Office Address*	*City*	*State & Zip Code*

2	FULL NAME OF INVENTOR	*Family Name*	*First Given Name*	*Second Given Name*
0	RESIDENCE & CITIZENSHIP	*City*	*State Or Foreign Country*	*Citizenship*
3	POST OFFICE ADDRESS	*Post Office Address*	*City*	*State & Zip Code*

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

SIGNATURE OF INVENTOR 201	*SIGNATURE OF INVENTOR 202*	*SIGNATURE OF INVENTOR 203*
Uwe Knauß		
DATE 20. Nov. 2000	*DATE*	*DATE*

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